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Where are all the Young Stars in Aquila?

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Abstract. The high Galactic longitude end of the Aquila Rift comprises the large Aquila molecular cloud complex, however, few young stars are known to be located in the area, and only one is directly associated with the Rift. In contrast, the Serpens star-forming region at the low Galactic longitude end of the Rift contains hundreds of young stars. We review studies of the raw molecular material and describe searches for young objects in the Aquila clouds. The characteristics of the known young stars and associated jets and outflows are also provided. Finally, we suggest some possible explanations for the dearth of star formation in this gas-rich region and propose some future observations to examine this mystery further.

1. Introduction

The Aquila Rift forms a great mass of dark clouds along the summer Milky Way through the constellations Aquila, Serpens, and eastern Ophiuchus. Large scale plates several degrees in diameter show almost a continuum of bright background stars along the Galactic plane with dark patches of nearly starless dark regions superimposed (e.g., Figure 1). This structure is silhouetted in the Hα images of Madsen & Reynolds (2005) and reflected in the H I map of Kawamura et al. (1999). Curiously, in spite of the resemblance of these dark clouds to other nearby, low-mass star-forming regions, few young stars have been identified in the eastern (higher Galactic longitude) portion of the Rift. By contrast, the western portion of the Aquila Rift contains the well-known Serpens star-forming region, near Galactic longitude 30° but substantially above the plane at a latitude of $\lesssim$5°.

In this paper we briefly review the results of millimeter and submillimeter surveys that include the eastern Aquila clouds (Section 2), describe the interesting characteristics of the region's known young stars (Section 3), discuss the best estimates for clouds' age, distance, and relationship with the known young stars in the area (Section 4), and speculate as to why much larger numbers of young stellar objects are not known to populate the region (Section 5). In Section 6 we propose a number of potential observations to determine better Aquila's star formation properties. In this chapter we will focus on the high Galactic longitude Aquila dark clouds. We will thus make a distinction between "Aquila", by which we mean the region within a few degrees of the Galactic

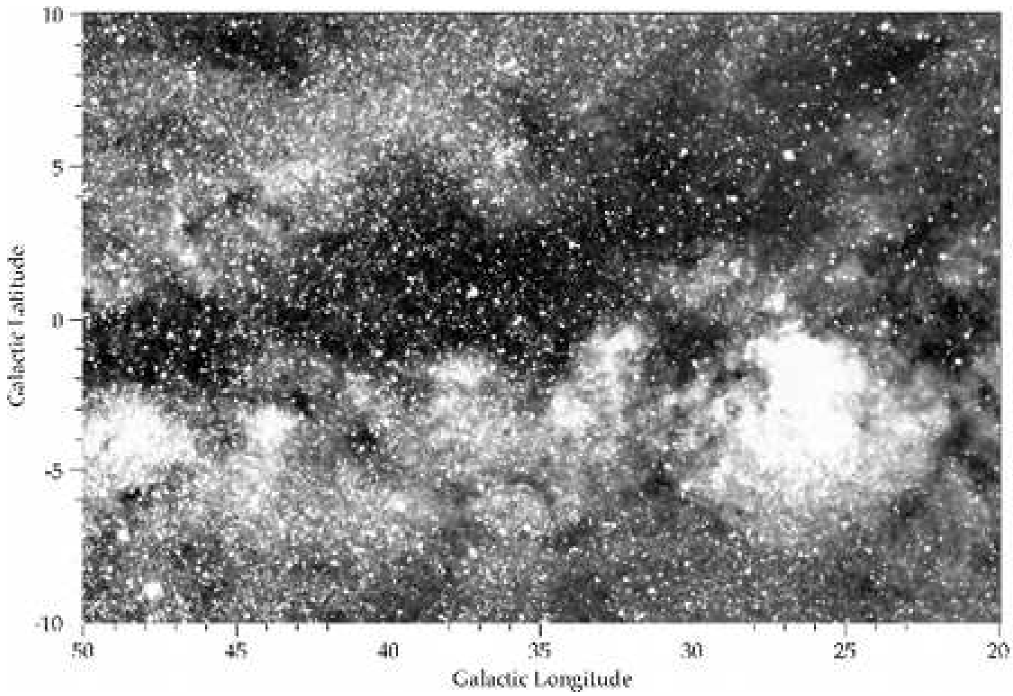

Figure 1. A visible light panorama of a portion of the first Galactic quadrant of the Milky Way taken by A. Mellinger (de Cicco 1999). The Aquila Rift is the dark structure oriented diagonally across the image.

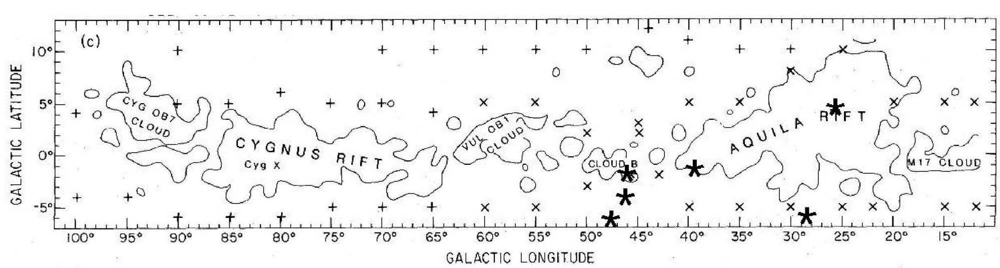

Figure 2. Broad features of the -10 to $+20$ km s^{-1} CO emission in the first Galactic quadrant. The approximate locations of the known young stars in Table 1 are indicated with asterisks. The location of the early type Serpens star MWC 297 ($l = 26.80^\circ$ and $b = +3.53^\circ$) is also marked. Plot from Dame & Thaddeus (1985).

plane located approximately between Galactic longitudes 30° and 50°, and the larger "Aquila Rift" cloud structure (see Section 2).

2. The Raw Materials: Millimeter and Submillimeter Surveys

The initial Galactic plane CO survey of Dame & Thaddeus (1985) identified the salient features of the Aquila Rift and established a connection between the dark nebulae and the molecular clouds in the region. Subsequent improvements to the initial survey

(Dame et al. 1987, 2001) increased the sensitivity by more than a factor of 10, increased the coverage of the CO observations from a 4° to a 10° strip in Galactic latitude, and increased the angular resolution to 1/8°. In Galactic coordinates, the Aquila Rift stretches from 20° to 40° in longitude and -1° to 10° in latitude, as demarcated by CO and 21 cm HI (Dame et al. 2001; Figure 2).

The molecular mass of the Aquila Rift as determined from CO observations has been estimated to be between $1.1{\times}10^5$ M$_\odot$ and $2.7{\times}10^5$ M$_\odot$ (Dame & Thaddeus 1985; Dame et al. 1987; Straižys et al. 2003). Using the molecular line widths and a uniform density sphere approximation, Dame & Thaddeus calculate the virial mass of the Aquila Rift to be $2.6{\times}10^5$ M$_\odot$. The virial mass is then about the same as or slightly greater than the observed mass, depending on the parameters used in the H_2 gas mass estimates, particularly the cloud distance and therefore size and density. The relationship between the virial mass and the observed mass reflects the star-forming potential of these clouds because, if the virial mass dominates, the cloud is dynamically unstable and unlikely to form stars (e.g., Solomon et al. 1987). Therefore, the ambiguity in the measured mass of the Aquila Rift is important to follow up with additional millimeter observations and improved distance measurements.

The Aquila Rift consists of numerous small and large clouds, many of which have been identified and tabulated by Lynds (1962). Unfortunately, the Lynds coordinates are sometimes so uncertain that it is not clear which cloud they refer to. Dobashi et al. (2005) have performed an extinction study of the Galactic plane using automated star counts, and they offer a list of clouds with finding charts and accurate coordinates.

Kawamura et al. (1999) used ^{12}CO observations to search for molecular clouds in the region to the Galactic south of the Aquila Rift. Although they identified dozens of small clouds, possibly dynamically connected to the Rift, no correlation with stellar $IRAS$ point sources was apparent. Kawamura et al. (2001) focussed on the region in the immediate vicinity of the T Tauri star HBC 294 (V536 Aql). They detected a ring shaped cloud in ^{12}CO ($l = 48.1^\circ$, $b = -6.3^\circ$), also seen in the Dame et al. (2001) survey, containing about 430 M$_\odot$ of gas, five ^{13}CO cores, and three C^{18}O cores. However, no candidate young stellar objects, as indicated by $IRAS$ fluxes, were found. Complementary objective prism observations did detect an Hα emission line object, which may be a young star, near the dark cloud LDN 694 (Kawamura et al. 2001).

Harvey et al. (2003) studied the properties of the candidate protostellar collapse core Barnard 335 in millimeter continuum and compared these data with prior observations of the core in CS (Wilner et al. 2000) and in NH_3 (Benson & Myers 1989; see also the chapter by Reipurth on Bok globules). This core is located only a few degrees from the molecular ring seen by Kawamura et al. (2001) and is associated with the dark cloud LDN 663 (see Figure 6 in Kawamura et al. 2001).

Additional millimeter and submillimeter surveys have been conducted, using both line and continuum emission, to search for signs of dense molecular and possibly prestellar cores in the Aquila Rift region. Anglada et al. (1997) focussed on NH_3 in areas where outflows had been previously detected in optical light and in molecular lines. Morata et al. (1997) observed CS in the region near the outflows in the filamentary dark cloud, about $15'$ north of the prominent T Tauri star AS 353 (Section 3.7). Their strongest detection of CS coincides with the location of the dark cloud, LDN 673 (Lynds 1962; Figure 3). Morata et al. (2003, 2005) analyzed the small-size structure of this region in a multitransitional study including interferometric maps. Kirk et al. (2005) used submillimeter JCMT observations to study five dark clouds in the area; no pre-

stellar cores were found in the four Lynds clouds in the sample. However, the object Barnard 133, located within about a degree of several known young stars just off the southern Galactic edge of the Aquila Rift, is not only a strong submillimeter source but also harbors an NH_3 core (Benson & Myers 1989). Visser et al. (2002) performed a large 850 μm survey of LDN 673 and found eight sources, SMM 1-8, some of which are associated with IRAS sources (see their Figure 20). Many ultra-compact HII regions, tracers of high mass star formation, are located throughout the Aquila Rift (Becker et al. 1994), however, their distances are ambiguous and the majority are likely to be background objects.

Abundant raw material appears to be available in the region, although few cores harboring active star formation have been identified. The few known young stars (Section 3) and star-forming cores are almost all scattered throughout the small molecular cloud clumps to the Galactic south of the Aquila Rift. The eastern portion of the Rift is apparently rich in gas but almost devoid of known star formation (Figure 4).

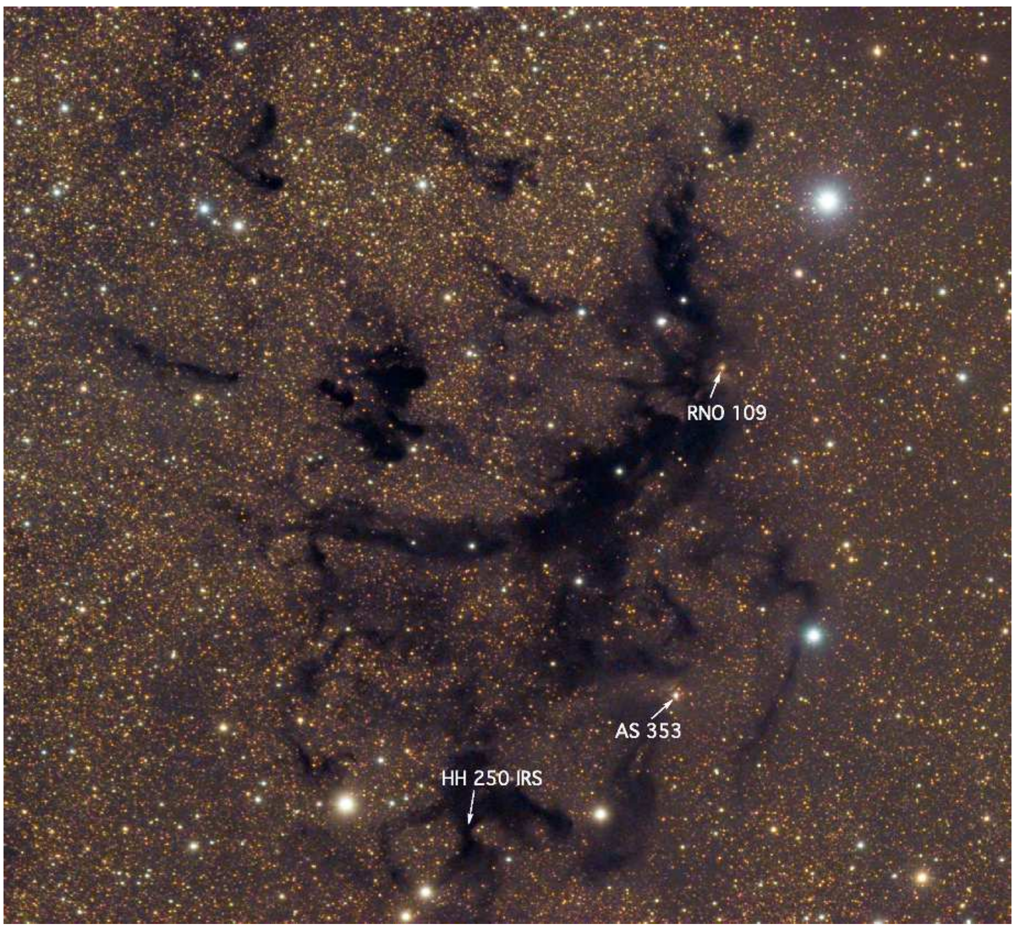

Figure 3. The LDN 673 cloud complex is highly fractured. The image is approximately 1 degree wide; north is up and east to the left. Courtesy of Bernhard Hubl.

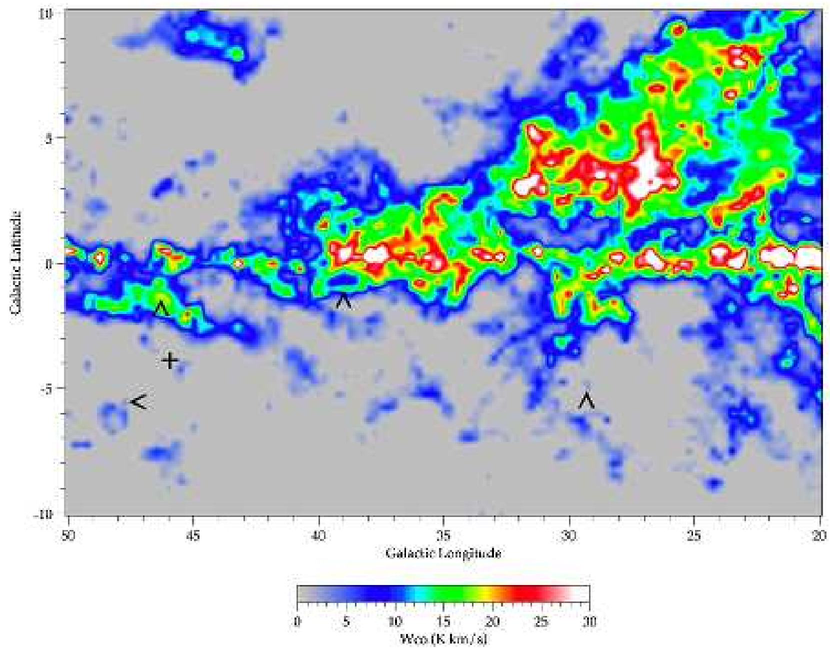

Figure 4. An integrated ^{12}CO map of the Aquila Rift, from $v_{LSR} = -30$ to $v_{LSR} = +30$ km s^{-1}. The high Galactic longitude sector of the Rift, from l of 33° to 41° and b of 3° to $-2°$ only contains one known young star, the unusual object HBC 684, on the lower extreme of the cloud. The Serpens star-forming region is located around $l \sim 30°$ and $b \sim 5°$. Arrows indicate molecular material associated with known young stars (Table 1). A cross shows the position of Parsamian 21.

3. The Known Stars: Visible and Infrared Studies

Several young objects in Aquila have been very well studied (Section 3.7), but the remainder of the known young stars have not received much attention until recently, although Cohen & Kuhi (1979) identified a few of them. Indeed, it is not yet known what the total stellar census may be in the region. Thé (1962) found several Hα emission-line objects towards Aquila and Scutum, however, followup spectroscopy is required to identify the nature of these detections. The known young Aquila stars are listed in Table 1 and their approximate positions illustrated in Figures 3 and 4.

Rice et al. (2006) have lately completed a high spectral resolution study in the infrared of all but one of the Aquila stars listed in the Herbig and Bell Catalogue (Herbig & Bell 1988; HBC). The exception, Parsamian 21, which has been described as a candidate FU Ori object (e.g., Staude & Neckel 1992), is the only potential higher-mass object in Aquila and may in fact actually be a background object at $\sim$2 kpc (Section 3.7). The initial goal of Rice et al. was to determine the radial velocities of the sample and to search for variability indicative of spectroscopic binaries. The study ultimately revealed a wealth of information about the low-mass targets.

3.1. Stellar Radial Velocities

Radial velocities can be used to strengthen the association among young stars in close spatial proximity on the sky. Rice et al. (2006) used high-resolution (R$\sim$30,000) H-band spectra of eight of the nine objects listed in Table 1 in order to determine radial velocities, rotational velocities, and spectral types, as well as to search for radial velocity variability that would indicate an angularly unresolved companion. The precision of the radial velocity measurements was estimated to be 2 km s^{-1}. The radial velocities were measured from high signal-to-noise ratio spectra (SNR$\sim$200$-$400) and from spectra typically obtained at multiple epochs. Although the young stars in Aquila are spread out over $\sim 20^\circ$ on the sky, the dispersion of the radial velocity measurements made by Rice et al. (2006) is about 2 km s^{-1}, suggesting that the stars formed from the same molecular cloud complex (e.g., Herbig 1977). The similar radial velocities of AS 353A (average of -11.4 km s^{-1} from three epochs) and AS 353B (-10.7 km s^{-1}, from one epoch), along with the common proper motions measured by Herbig & Jones (1983), indicate that this system is physically related. The average radial velocity for eight of the objects studied was -8.6 km s^{-1}; a ninth object, HBC 682, was significantly variable in radial velocity and is hence a spectroscopic binary candidate. The $v\sin i$ rotational velocities of this sample measured by Rice et al. (2006) range from 10 km s^{-1} to 50 km s^{-1}.

3.2. X-Ray Properties

X-ray luminosity in young stars is thought to be thermal emission from gas heated by magnetic reconnection events between the magnetic field of the star and that of the circumstellar disk. Surveys of nearby star-forming regions reveal dozens or hundreds of X-ray sources, associated mainly with weak-line T Tauri stars (Feigelson & Montmerle 1999 and references therein). Queries of the *ROSAT*, Chandra, and XMM/Newton archives using HEASARC reveal only two sources within 5 arcminutes of any of the coordinates listed in Table 1. Both of these sources were found in the *ROSAT* All-Sky Survey (RASS) Faint Source Catalog (Voges et al. 2000). All RASS sources were observed for an average of $\sim$500 seconds and with a detection limit of 6 photons (Belloni et al. 1994). One detected source near the young stars in Aquila lies within 1 arcminute of FG Aql/G1, FG Aql/G2, FG Aql/G3, and FH Aql, and the second source is about 3 arcminutes from HBC 684. Both of these sources have hardness ratios consistent with that of known T Tauri stars (e.g. Neuhäuser et al. 1995, Kastner et al. 2003). The

Table 1. Known Young Aquila Stars

Object	HBC	RA (J2000)	DEC	l, b (°, °)	SpTy	V mag
FG Aql/G1	681	19 02 22.2	−05 36 20	29.17, −4.98	K5	13.7
FG Aql/G3	...	19 02 22.6	−05 36 22	29.17, −4.98	M0	15.5
FG Aql/G2	682	19 02 22.8	−05 36 15	29.18, −4.98	K5	13.6
FH Aql	683	19 02 23.2	−05 36 37	29.17, −4.98	K7	15.5
*IRAS*19046+0508	684	19 07 09.8	+05 13 10	39.37, −1.11	K5	15.5
AS 353A	292	19 20 31.0	+11 01 54	46.05, −1.33	K5	12.5
AS 353B	685	19 20 31.0	+11 01 49	46.05, −1.33	M0	14.6
Parsamian 21	687	19 29 00.7	+09 38 39	45.82, −3.83	F5	14.2
V536 Aql	294	19 38 57.4	+10 30 16	47.75, −5.57	K7	14.9

only Chandra observations near any of the Table 1 objects are more than 30 arcminutes away, and the nearest XMM/Newton observation is more than 70 arcminutes away.

3.3. Extinction

Typical stellar extinctions found by Rice et al. (2006) range from $A_v \sim 0 - 4$ magnitudes. Based on the *2MASS* JHK magnitudes, these represent interstellar extinction to the scattering surface of the stellar system (i.e. circumstellar disks and shells) and may underestimate the total extinction to the stellar photosphere in the presence of circumstellar material (e.g., Section 4.2, Prato et al. 2003). In general, the values of interstellar extinction to the Aquila young stars are consistent with the typical values found for the region's molecular clouds, suggesting a similar distance. The dust maps of Schlegel et al. (1998) indicate an upper limit on the extinction in the Aquila Rift of $A_v \sim 5$ magnitudes (Drew et al. 2005). Dobashi et al. (2005) find maximum extinctions along the Aquila Rift of 5$-$10 magnitudes. The photometric study of $\sim$500 stars by Straižys et al. (2003) suggests a maximum A_v of about 3.0 magnitudes throughout the Rift and a distance to the front edge of the clouds of 225 $\pm$55 pc (Section 4.1).

3.4. Multiplicity

The multiplicity among the few known young Aquila stars appears comparable to that of Taurus, the nearby star-forming region with the highest binary fraction (e.g., Ghez et al. 1993; Simon et al. 1995). For the nine systems listed in Table 1, there are a total of at least 14 primary and companion objects. HBC 681 and HBC 682 were identified as visual binaries by Rice et al. (2006) for the first time. HBC 682A is also a candidate spectroscopic binary (Rice et al.). The HBC 294 system is a known, subarcsecond binary (Ageorges et al. 1994) and AS 353 a known hierarchical triple (Tokunaga et al. 2004).

3.5. Circumstellar Disks

Most of the objects in Table 1 lie in the region of the J$-$H vs. H$-$K color-color diagram characterized by an IR excess (Figure 5), indicating the likelihood of abundant circumstellar disk material in these systems. In particular, Figure 5 shows that AS 353A and HBC 687 (Parsamian 21) both lie *below* the classical T Tauri star locus. This may be an indication of abundant reflected light from circumstellar material. Parsamian 21 is probably a background FU Ori type object with an unusually massive disk (Staude & Neckel 1992). The circumstellar disk of AS 353A has been well-studied; this system is one of the most active and visually bright T Tauri stars known (e.g., Tokunaga et al. 2004 and references therein). HBC 684 is a unique emission line object, possibly surrounded by a massive disk. It is by far the reddest object in Table 1. FG Aql/G1, FG Aql/G2, and V536 Aql all exhibit the ordinary behavior of classical T Tauri stars with ongoing accretion from a circumstellar disk. In summary, like the multiplicity fraction, the circumstellar disk fraction of this group of stars is relatively high compared to other nearby star-forming regions. Several of these systems are discussed in detail in Section 3.7.

3.6. Herbig-Haro Jets and Outflows

Herbig-Haro flows are signposts of recent star formation, and they are thus of great interest in identifying very young stars. A detailed discussion of HH flows and their

energy sources can be found in Reipurth & Bally (2001). While the Aquila clouds are too large to have been fully surveyed by CCD images, the Palomar Schmidt plates have been examined and CCD images have been obtained of regions around the known young stars. As a result, a number of HH objects are known in Aquila, and they are discussed individually below.

HH 32 from AS 353A HH 32 is a bright HH object originating in AS 353A; it was discovered by Herbig (1974). It consists of two main bow shocks, HH 32A and 32B. HH 32 is a high-excitation HH object for which optical spectroscopy has been reported by Dopita (1978), Brugel, Böhm, & Mannery (1981a,b), Herbig & Jones (1983), Solf, Böhm, & Raga (1986), and Hartigan, Mundt, & Stocke (1986). Ultraviolet spectroscopy was reported by Böhm & Böhm-Vitense (1984) and Lee et al. (1988). HH 32 is one of the rather rare red-shifted HH objects, and the radial velocity measurements, combined with proper motions determined by Herbig & Jones (1983) and Curiel et al. (1997), show that it moves away from AS 353A with a space velocity of about

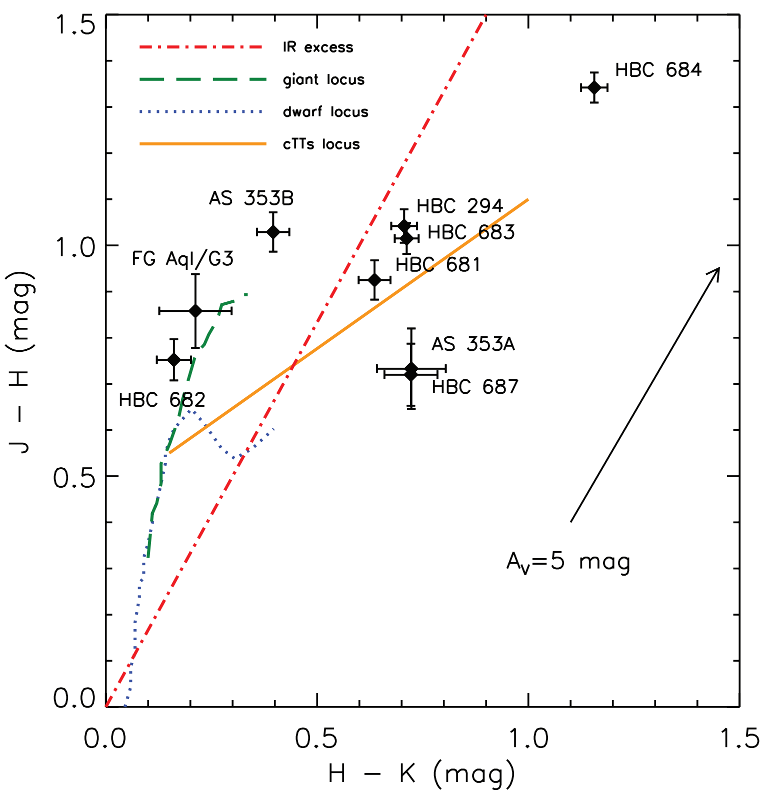

Figure 5. $J - H$ versus $H - K$ color-color diagram for the objects in Table 1. Magnitudes are from *2MASS* and the error bars represent the propagated photometric uncertainties reported in the that catalog. The dash-dot line separates objects with (to the right) and without IR-excess. The cTTs (solid line), dwarf (dotted line), and giant (dashed line) loci are the same as in Figure 4 of Prato et al. 2003 but transformed in to the *2MASS* magnitude scale using equations from Carpenter 2001. The effect on observed color of 5 magnitudes of visual extinction is represented by the arrow (thick line), using the equation derived by Prato et al. 2003.

300 km s^{-1} at an angle of about 70° to the plane of the sky. The fine details of this HH flow are seen in the HST images of Curiel et al. (1997; Figure 6). Beck et al. (2004) obtained an integral field unit data cube for HH 32, providing the hitherto most detailed spectroscopic and kinematic study of this HH flow. These data were modelled by Raga et al. (2004) in terms of the internal working surface model. Mundt, Stocke, & Stockman (1983) found a third flow component, HH 32C, on the opposite side of AS 353A with high blue-shifted velocities, indicating that HH 32 is a bipolar flow.

Edwards & Snell (1982) observed high-velocity CO emission associated with AS 353A and the HH 32 flow. HH 32 is one of the few HH objects detected in the radio continuum (Anglada et al. 1992, 1998). It also emits in the infrared H_2 lines (Davis, Eislöffel, & Smith 1996, and references therein). Davis et al. (1996) report three faint HH knots, HH 332, about an arcminute south-west of HH 32, but not on the well-defined flow axis of HH 32. Tokunaga et al. (2004) argue that these are likely to be part of an earlier precessing flow component of HH 32, since the flow is significantly foreshortened, so a small angle in flow direction projects to a much larger angle on the sky.

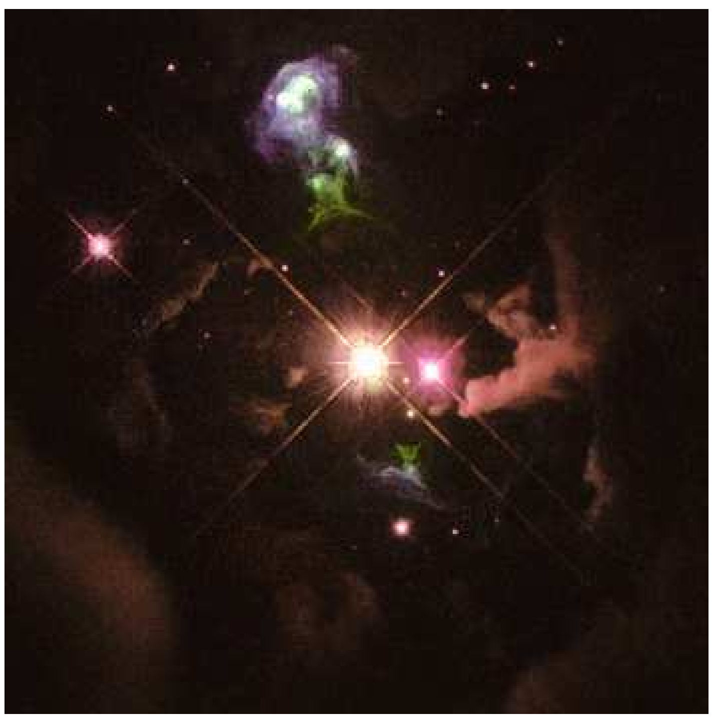

Figure 6. AS 353A and B together with the bipolar HH 32 flow as seen with the HST. The young stars have created a wind-blown cavity in their natal cloud, seen in reflected light. Composite image from R, Hα, [NII], and [SII] images. From Curiel et al. (1997).

HH 250 from IRAS 19190+1048 About 14 arcminutes southeast of HH 32, Devine, Reipurth, & Bally (1997) discovered a rather bright compact bow shock facing away from the embedded IRAS source 19190+1048. Another fainter HH knot is found closer

to the source, and two diffuse reflection nebulae surround the source. The energy distribution of the IRAS source suggests that it is a Class I object.

RNO 109 Within the cloud LDN 673, Armstrong & Winnewisser (1989) reported the discovery of a molecular outflow associated with a small nebulosity, RNO 109, a feature associated with the IRAS point source 19180+1116 (Cohen 1980) and having colors characteristic of a probable embedded young stellar object. Coordinates for this object are poorly defined and no spectra are available in the literature. Thus, we do not include RNO 109 in Table 1. Another nearby source, IRAS 19180+1114, also drives an outflow (Visser et al. 2002). This region is only a few degrees from the AS 353 system and located within the same molecular cloud condensation (Figure 3). The outflow was observed in CO and ^{13}CO and extends over 10−15 square arcminutes. Morata et al. (1997) observed this outflow in CS gas, and Anglada et al. (1997) in NH_3.

HH 119 The Bok globule B335 is associated with HH object 119 (e.g., Reipurth et al. 1992). This system is discussed in depth in the chapter on Bok globules by Reipurth.

HH 387 Hirth et al. (1997) first identified HH 387, associated with the subarcsecond binary V536 Aql (Section 3.7), as a small jet with a 3−4 arcsecond extent and PA of 90°. Mundt & Eislöffel (1998) confirmed their findings and, imaging the system in [SII], identified knots in the jet as far as 16 arcseconds away at a PA of 110°. A very faint counter jet is suggested in the data of Mundt & Eislöffel that requires further confirmation.

HH 221 A very small jet-like feature is present along the polar axis of the conical nebula associated with Parsamian 21 (Staude & Neckel 1992). However, it is unlikely that this object is a true Aquila member and is more probably at a distance of ∼2 kpc.

3.7. Notes on Individual Stars

AS 353 By far the best known young star in the Aquila region is AS 353 (Figure 6), originally discovered by Merrill & Burwell (1950), and later independently in the survey of Iriarte & Chavira (1956). The associated outflow, HH 32, is discussed in Section 3.6. Given the brightness (V∼12.5) of AS 353, it can be studied in great detail. Herbig & Jones (1983) provided the first detailed discussion of the emission line spectrum of AS 353A, and Mundt, Stocke, & Stockman (1983) presented high-resolution Hα and sodium doublet spectra, documenting the massive, high-velocity, neutral wind of the star. Further echelle spectra demonstrated that the Hα profile shows significant variability (Hartigan, Mundt & Stocke 1986). In their study of AS 353A, Böhm & Raga (1987) presented spectrophotometry from 3,300 Å to 10,000 Å and noted the strong ultraviolet excess of the star. In a subsequent and more detailed study, Eislöffel, Solf, & Böhm (1990) presented fluxes of all emission lines in about the same spectral range but with higher spectral resolution. AS 353A has been part of numerous optical spectral studies of T Tauri stars since then, including Hamann & Persson (1992), Hamann (1994), and Edwards et al. (1994). In the near-infrared region, AS 353A shows the 2.3 μm CO band in emission (Carr 1989; Biscaya et al. 1997; Prato et al. 2003; Rice et al. 2006) as well as other emission lines (e.g., Davis et al. 2003; Prato et al. 2003). The stellar continuum is so heavily veiled that a photospheric spectrum cannot be easily

seen, although Basri & Batalha (1990) suggested a spectral type of K2. Recent multi-epoch high-resolution H-band spectra revealed the stellar photospheric features of a K5 spectral type star (Rice et al. 2006).

AS 353A displays considerable photometric variability (e.g., Fernández & Eiroa 1996). Its near- and mid-infrared photometry is summarized by Rice et al. (2006) and Molinari, Liseau, & Lorenzetti (1993). IRAS observations are discussed by Cohen & Schwartz (1987), sub-millimeter observations are reported in Reipurth et al. (1993), and centimeter data are given by Anglada et al. (1998). AS 353A forms a triple system with the less well-studied AS 353B, a weak-line T Tauri star binary of separation 0.24 arcseconds (Tokunaga et al. 2004).

HBC 684 HBC 684 is a spectacularly peculiar object. No photospheric absorption lines were detected even in high-dispersion H- and K-band spectra, but it was possible to measure a radial velocity, consistent with the other Aquila young star velocities, using the pure atomic metal emission spectrum observed in this object in three H-band epochs spanning more than a year (Rice et al. 2006). An emission line spectrum was also observed in visible light two years after the infrared observations, revealing a broad P Cygni Hα profile with a $\sim$200 km s^{-1} absorption trough. HBC 684 is the most extinguished Aquila object known and shows one of the strongest infrared excesses (Figure 5); it is coincident with the IRAS source 19046+0508. The line ratios *in emission* are consistent with a K5 spectral type object. Rice et al. (2006) provide a detailed discussion of this object and speculate as to the origin of its unusual spectrum.

HBC 294 Ageorges et al. (1994) first discovered HBC 294 to be a binary with an $0\farcs52$ separation at a position angle of 17°. HBC 294 is a typical, classical T Tauri star, with Brγ and Paβ emission detected in near-infrared spectra, Hα and forbidden emission lines seen in visible light, and a near-infrared excess, all indicative of accretion from a circumstellar disk and disk-driven outflows associated with at least one of the stars (Rice et al. 2006; Hamann 1994). The *IRAS* PSC flux measurements of HBC 294 (IRAS 19365+1023) reveal even greater mid- to far-IR fluxes than those of AS 353A at all but 100 μm (Weaver & Jones 1992). The lower 100 μm flux suggests that the disk(s) may be truncated by the binary.

Parsamian 21 Parsamian 21, or Par 21, was initially identified by Parsamian (1965) from the Palomar Sky Survey plates during a search for cometary nebulae. Dibai (1969) identified the associated star as type A5V, and Cohen (1974) observed the system in the mid-infrared and found N- and Q-band magnitudes of 3.7 and 1.4, respectively. It is associated with the source IRAS 19266+0932. Digital sky survey plates show an unusual and complex nebulosity. If this represents half of a conical, bipolar structure, a high degree of obscuration must block the unseen portion of the nebula. Neckel & Staude (1984) concurred with the A5V spectral type designation, however, in a later paper (Staude & Neckel 1992), they identified FU Orionis characteristics in the spectrum of Par 21 and re-classified the type as F5Iab. The visible light spectrum of the photosphere is characterized by broad absorption lines and in particular a prominent P Cygni profile with an absorption trough of width $\sim$450 km s^{-1} (Greene, Aspin, & Reipurth 2008). Evidence in the form of 1.3 mm emission (Henning et al. 1998), prominent disk-pattern polarization (Draper et al. 1985), strong near- and mid-infrared excesses (e.g., Cohen 1974), and water ice absorption and crystalline silicate emission (Polomski et al. 2005) point to the presence of a massive circumstellar disk. Given the luminosity of this sys-

tem, it is unlikely to be located in Aquila and is most probably at a distance of 1.8 kpc (Staude & Neckel 1992).

4. Putting It All Together

4.1. Distance

For the AS 353 system in Aquila, Prato et al. (2003) adopted a distance estimate of 150 $\pm$50 pc. Earlier estimates for the distance to the Aquila Rift range from 110 pc (Weaver 1949) to 150 pc (Edwards & Snell 1982) to 200 pc (Dame & Thaddeus 1985). Herbig & Jones (1983) estimated the distance to LDN 673 to be 300 pc and noted that LDN 673 is foreground to "the very extensive Aquila obscuration." If the Aquila young stars are indeed associated with the Aquila Rift and are therefore connected with the Serpens region, then the distance of Serpens is also germane. Unfortunately, this number also has a history of uncertainty. Racine (1968) and Strom et al. (1974) estimated a distance of 440 pc to Serpens through studies of the star HD 170634. Both groups determined an early spectral type, B7V and A0V, respectively, and applied a small reddening correction, based respectively on visible and infrared light, to derive the distance modulus. De Lara et al. (1991) combined infrared photometry and visible light spectroscopy of five stars in Serpens, yielding an improved average distance modulus and a distance of 311 pc. Recently, Straižys et al. (2003), using two-dimensional photometric classification of stars in the seven-color Vilnius system, estimated a distance of 225 $\pm$55 pc. Eiroa et al., in the chapter on Serpens, adopt a distance of 230 $\pm$20 pc to the Serpens region. This appears to be based on a rough average of recently derived values, including unpublished estimates from 2MASS data and associated extinctions. We note that recent distance determinations to Serpens are not only dropping, but are also converging with estimates for the Rift in general, and for the Aquila young stars specifically. For now we adopt a distance of 200 $\pm$30 pc to Aquila, as in Rice et al. (2006), and stress the importance of future observations to determine this quantity accurately (Section 6).

4.2. Age

A number of indications point to a young age for the Aquila stars, including the high circumstellar disk fraction, the striking Herbig-Haro jets driven by several energetic sources, and the possible association with the Serpens cluster (age $\sim$1 Myr; Winston et al. 2005). Based on the evolutionary models of Palla & Stahler (1999), Prato et al. (2003) and Rice et al. (2006) determined ages for the known young stars (Section 3) of at most a few Myr, with the exception of FG Aql/G3 which may be older than 10 Myr. Ages derived for this sample from the models of Baraffe et al. (1998) are similar. Although these stars span a broad area on the sky, their approximately common ages and similar radial velocities suggest origins in the same cloud complex.

4.3. Star Formation in Aquila

Molecular maps of the Galactic plane region show that there is at least low-intensity CO emission at the location of all the known young Aquila stars (Figure 4). However, they are spread out over a large area (30$\times$60 pc, assuming d=200 pc). The CO with which they appear to be associated is clumpy and filamentary. The stars are all located below the Galactic plane while the bulk of gas present in the Aquila cloud extends along and to the north of the Galactic plane. Furthermore, there exists a complex velocity structure

within the Rift; a velocity break in the CO at about $l = 33^\circ$ appears to indicate a demarcation between two distinct sets of clouds (Figure 7). This break might account for the double-peaked CO lines seen by White, Casali, & Eiroa (1995).

As shown by Rice et al. (2006; Section 3.1), the rms of the Aquila young stars' radial velocities is only $\sim$2 km s^{-1}, suggestive of an origin in cloud cores of similar velocities. The LSR velocities of the stars fall between 15.5 and 17.5 km s^{-1}, and those of the molecular cloud material in closest proximity are ~ 10 km s^{-1} (Figure 7). It seems unlikely that these fairly young stars are unrelated, however additional work remains in order to understand how the stars are associated with each other and with the local molecular material. We discuss some suggestions for future research in Section 6. One of the major mysteries in this region remains the question of why there are not more young stars present. We address this in Section 5.

4.4. Vulpecula and Scutum

Further along the Galactic plane at longitudes $l \sim 55{-}63^\circ$ lies the Vulpecula molecular cloud. Most studies of Vulpecula have focussed on the open cluster in the cloud, NGC 6823; at a distance of $\sim 2 - 2.5$ kpc (Massey 1998) only the higher mass stars in this cluster have been well studied (e.g., Massey et al. 1995). Kumar et al. (2004) estimate the age of NGC 6823 at around 3 Myr, similar to the estimate of Peña et al. (2003) and consistent with the range, $2{-}7$ Myr, determined by Massey (1998). However, it is not clear that the open cluster and the Vulpecula cloud are associated. Dame & Thaddeus (1985) note that there are two distinct distance scales for this region – that of the OB1 association (NGC 6823), 2.3 kpc, and that of the local dust, $\sim$400 pc (Neckel et al. 1980). The cluster is likely background to the molecular cloud.

Given the large difference in distance between either the dust or the OB1 association in Vulpecula and the stars and gas in the Aquila region, it is unlikely that there is any direct relationship between these clouds. Vulpecula falls into an interstice between two Galactic spiral arms, roughly in the direction of the Sun's motion into the first quadrant of the Galaxy (Frisch 1998). This provides a direct line of sight to the high-mass cluster and recommends it for further study.

The Scutum region lies a couple degrees below the Galactic plane, just south of the Aquila Rift cloud in an apparent hole in the molecular gas associated with the Rift. The molecular gas velocities of clouds in the direction of Scutum, at $40{-}120$ km s^{-1}, are very distinct from those of the Aquila Rift (Dame et al. 1986). Santos et al. (2005) describe the open cluster, M11 (NGC 6705), at a distance of 1.9 kpc, as superimposed on the Scutum region. Madsen & Reynolds (2005) used hydrogen emission lines to study the gas in the Scutum region. They conclude that this region is seen, at a distance of $\sim$6 kpc with only $\sim$3 magnitudes of visual extinction, through a gap in the more local molecular clouds, and is associated with ionized gas in the inner Galaxy.

5. Where Are All the Young Stars?

Based on the very young ages of the observed stars in Aquila, and the abundance of raw materials for star formation present in the region, it is surprising that much larger numbers of young sources are not found. Why did the initial epoch of star formation in this region produce so little? The Serpens star-forming region in the western part of the Aquila Rift is rich with hundreds of young stars (see chapter by Eiroa et al.). At Galactic longitude 33°, a distinct shift in the velocity of the ^{12}CO gas appears to

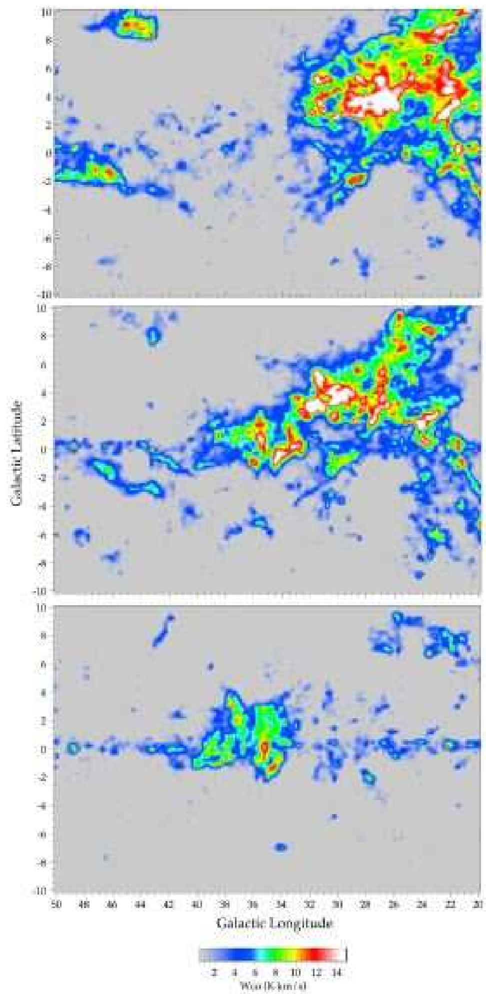

Figure 7. ^{12}CO maps integrated over 5 km s $^{-1}$ intervals; the top one centered at 5 km s $^{-1}$, the middle one at 10 km s $^{-1}$, and the bottom one at 15 km s $^{-1}$. Note the velocity break at $l \sim 33^\circ$. The young stars discussed in Section 3 are all associated with molecular material with a $v_{lsr} \sim 10$ km s $^{-1}$ (see also Figure 4).

demarcate a boundary not only between Serpens and Aquila, but between young star rich and poor regions, respectively (Figure 7).

Why is this the case? Particularly striking is the eastern portion of the Rift that harbors only HBC 684 as far as we know. Possibly large numbers of younger, embedded objects exist within the eastern Rift but have so far evaded detection. This bears further attention, possibly in the form of Spitzer surveys, specifically of the eastern Rift which appears to be gas-rich but young star poor. Surveys for pre-stellar cores south of the eastern Rift have not revealed a large population.

The small sample of young stars in the TW Hydrae Association (e.g. Rich et al. 1999) are also spread out over an area of about 30 pc in diameter (Feigelson & Montmerle 1999). Aquila could comprise a similar sort of small association. TW Hydrae members have ages of $\sim$10 Myr; it is conceivable, even likely, that the TW Hya stars formed in a much more compact region and have dispersed over a large area over millions of years. In the case of the sparse population of Aquila stars, however, their $\sim$1 Myr ages imply that a similar scenario is unlikely. Furthermore, at least the partially embedded stars such as AS 353 appear to be located close to where they were formed. Thus, the pre-main sequence population in Aquila seems to be comprised of numerous small pockets of star formation.

Frisch (1998) describes the properties of the local interstellar medium within 500 pc of the Sun and points out that the "*Aquila Rift molecular cloud is the node region where all of the superbubble shells from the three epochs of star formation in the Scorpius-Centaurus Association, as well as the most recent supernova explosion creating the North Polar Spur, converged after plowing into the molecular gas and decelerating.*" Could these dynamical processes in the Aquila region be responsible for the disruption of star formation? Or, alternatively, could such processes have triggered only a very limited epoch of star formation? Without a much more exact study and a comprehensive picture of the gas dynamics of the region, it is not possible to evaluate these scenarios; however, they remain intriguing possibilities.

A more mundane explanation for the dearth of young stars in the Aquila molecular cloud may be simply that star formation has, so far, only proceeded in isolated pockets. If in the region of Aquila that lies south of the Galactic plane the virial mass exceeded the total gas mass, the complex may have broken up just before or while forming a sporadic distribution of stars. This is not a fully satisfactory scenario, however, because ample raw materials abound in the eastern Rift (Section 2). Perhaps we have simply not yet determined the absolute census of young Aquila objects; the location of these CO clouds in the Galactic plane comes with contamination from a dense stellar field within which it is highly non-trivial to pick out T Tauri stars (Figure 1). Although this is a challenging undertaking, a detailed survey for young stellar objects may be the most important next step in furthering our understanding of star formation in Aquila (Section 6).

6. Future Observations: A Complete Census of Aquila Young Stars

Objective prism and narrow-band Hα imaging surveys in Aquila should reveal emission line objects, typically associated with accreting young stars. Given the high disk fraction (Section 3.5) among the known young candidate members, this should reveal a significant portion of the pre-main sequence stellar population, if indeed it is there.

A complementary approach would be to use long-wavelength Spitzer observations to detect directly the warm dust in the circumstellar disks of embedded protostars.

In the spirit of stellar characterization, it would be profitable to understand the true space motions of the known young Aquila stars (Ducourant et al. 2005). By determining proper motions and combining these with the recently measured radial velocities, we will be able to determine the dynamical history of the young stars with far more accuracy.

For those known pre-main sequence stars that are also sufficiently energetic radio sources (e.g., AS 353), very long baseline interferometry can be used to determine very precise stellar distances. There currently exists an age-distance degeneracy for the Aquila young stars, although the obvious signatures of youth constrain them to be below a few Myr. Accurate distance determinations would localize not only the stars themselves, but also the associated molecular gas.

Millimeter wave surveys at higher angular resolution using isotopes and species which trace the denser regions of gas will provide a more complete picture of the structure and dynamics of the Aquila clouds and of how this region connects to the western part of the Aquila Rift, concurrent with the Serpens star-forming region. Some preliminary observations of $C^{18}O$ show that the distribution of this tracer of denser gas is very different from that of ^{12}CO. Cores revealed by such observations may provide a guide for the most productive areas in which to search for new or on-going star formation.

The Aquila region is rich, complex, and relatively nearby and merits continued attention and study.

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References

Ageorges, N., Ménard, F., Monin, J.-L., & Eckart, A. 1994, A&A, 283, L5
Anglada, G., Rodríguez, L. F., Canto, J., Estalella, R., & Torrelles, J. M. 1992, ApJ, 395, 494
Anglada, G., Sepulveda, I., & Gomez, J. F. 1997, A&AS, 121, 255
Anglada, G., Villuendas, E., Estalella, R., Beltrán, M. T., Rodríguez, L. F., Torrelles, J. M., & Curiel, S. 1998, AJ, 116, 2953
Armstrong, J. T. & Winnewisser, G. 1989, A&A, 210, 373
Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 1998, A&A, 337, 403
Basri, G. & Batalha, C. 1990, ApJ, 363, 654
Beck, T. L., Riera, A., Raga, A. C., & Aspin, C. 2004, AJ, 127, 408
Becker, R. H., White, R. C., Helfand, D. J., & Zoonematkermani, S. 1994, ApJS, 91, 347
Belloni, T., Hasinger, G., & Izzo, C. 1994, A&A, 283, 1037
Benson, P. J. & Myers, P. C. 1989, ApJS, 71, 89

Biscaya, A. M., Rieke, G. H., Narayanan, G., Luhman, K. L., & Young, E. T. 1997, ApJ, 491, 359
Böhm, K.-H. & Böhm-Vitense, E. 1984, ApJ, 277, 216
Böhm, K.-H. & Raga, A. C. 1987, PASP, 99, 265
Brugel, E.W., Böhm, K.-H., & Mannery, E. 1981a, ApJS, 47, 117
Brugel, E. W., Böhm, K.-H., & Mannery, E. 1981b, ApJ, 243, 874
Carpenter, J. M. 2001, AJ, 121, 2851
Carr, J. S. 1989, ApJ, 345, 522
Cohen, M. 1974, PASP, 86, 813
Cohen, M. & Kuhi, L. V. 1979, ApJS, 41 743
Cohen, M. 1980, AJ, 85, 29
Cohen, M. & Schwartz, R. D. 1987, ApJ, 316, 311
Curiel, S., Raga, A., Raymond, J., Noriega-Crespo, A., Cantó, J. 1997, AJ, 114, 2736
Dame, T. M. & Thaddeus, P. 1985, ApJ, 297, 751
Dame, T. M., Elmegreen, B. G., Cohen, R. S., & Thaddeus, P. 1986, ApJ, 305, 892
Dame, T. M., Ungerechts, H., Cohen, R. S., de Geus, E. J., Grenier, I. A., et al. 1987, ApJ, 322, 706
Dame, T. M., Hartmann, D., & Thaddeus, P. 2001, ApJ, 547, 792
Davis, C. J., Eislöffel, J., & Smith, M.D. 1996, ApJ, 463, 246
Davis, C. J., Whelan, E., Ray, T. P., & Chrysostomou, A. 2003, A&A, 397, 693
de Cicco, D. 1999, S&T, 98, 5, p. 137
de Lara, E., Chavarria-K, C., & López-Molina, G. 1991, A&A, 243, 139
Devine, D., Reipurth, B., & Bally, J. 1997, in *Low Mass Star Formation - from Infall to Outflow*, poster proceedings of IAU Symp. No. 182, eds. F. Malbet & A. Castets, p. 91
Dibai, E. A. 1969, Astrofizika, 5, 249 (English transl. Astrophysics, 5, 115)
Dobashi, K., Uehara, H., Kandori, R., Sakurai, T., Kaiden, M., Umemoto, T., & Sato, F. 2005, PASJ, 57, S1
Dopita, M. A. 1978, ApJS, 37, 117
Draper, P. W., Warren-Smith, R. F., & Scarrott, S. M. 1985, MNRAS, 212, 1P
Drew, J. E., Busfield, G., Hoare, M. G., Nurdoch, K. A., Nixon, C. A., & Oudmaijer, R. D. 1997, MNRAS, 286, 538
Drew, J. E., Greimel, R., Irwin, M. J., Aungwerojwit, A., Barlow, M. J., et al. 2005, MNRAS, 362, 753
Ducourant, C., Teixeira, R., Périé, J. P., Lecampion, J. F., Guibert, J., & Sartori, M. J. 2005, A&A, 438, 769
Edwards, S. & Snell, R. L. 1982, ApJ, 261, 151
Edwards, S., Hartigan, P., Ghandour, L., & Andrulis, C. 1994, AJ, 108, 1056
Eislöffel, J., Solf, J., & Böhm, K.-H. 1990, A&A, 237, 369
Feigelson, E. D. & Montmerle, Th. 1999, ARAA, 37, 363
Fernández, M. & Eiroa, C. 1996, A&A, 310, 143
Frisch, P. C. 1998, in IAU Colloq. 166, *The Local Bubble and Beyond*, ed. D. Breitschwerdt, M. Freyberg, & J. Trumper (Berlin: Springer), 269
Ghez, A., Neugebauer, G., & Matthews, K. 1993, AJ, 106, 2005
Greene, T.P., Aspin, C., & Reipurth, B. 2008, AJ, 135, 1421
Hamann, F. 1994, ApJS, 93, 485
Hamann, F. & Persson, S. E. 1992, ApJS, 82, 247
Hartigan, P., Mundt, R., & Stocke, J. 1986, AJ, 91, 1357
Harvey, D. W. A., Wilner, D. J., Myers, P. C., Tafalla, M., & Mardones, D. 2003, ApJ, 583, 809
Henning, T., Burkert, A., Launhardt, R., Leinert, C., & Stecklum, B. 1998, A&A, 336, 565
Herbig, G. H. 1974, Lick Obs. Bull. No. 658
Herbig, G. H. 1977, ApJ, 214, 747
Herbig, G. H. & Rao, N. K. 1972, ApJ, 174, 401
Herbig, G. H. & Jones, B. F. 1983, AJ, 88, 1040
Herbig, G. H. & Bell, K. R. 1988, Lick Obs. Bull. No. 1111
Hirth, G. A., Mundt, R., & Solf, J. 1997, A&AS, 126, 437

Iriarte, B. & Chavira, E. 1956, Bol. Obs. Tonantzintla y Tacubaya, 2, part 14, 31
Kastner, J. H., Crigger, L., Rich, M., & Weintraub, D. A. 2003, ApJ, 585, 878
Kawamura, A., Onishi, T., Mizuno, A., Ogawa, H., & Fukui, Y. 1999, PASJ, 51, 851
Kawamura, A., Kun, M., Onishi, T., Vavrek, R., Domsa, I., et al. 2001, PASJ, 53, 1097
Kirk, J. M., Ward-Thompson, D., & André, P. 2005, MNRAS, 360, 1506
Kumar, B., Sagar, R., Sanwal, B. B., & Bessell, M. S. 2004, MNRAS, 353, 991
Lee, M. G., Böhm, K.-H., Temple, S. D., Raga, A. C., Mateo, M. L., Brugel, E. W., & Mundt, R. 1988, AJ, 96, 1690
Lynds, B. T. 1962, ApJS, 7, 1
Madsen, G. J. & Reynolds, R. J. 2005, ApJ, 630, 925
Massey, P., Armandroff, T. E., Pyke, R., Patel, K., & Wilson, C. D. 1995, AJ, 110, 2715
Massey, P. 1998, in ASP Conf. Ser. 142, *The Stellar Initial Mass Function*, ed. G. Gilmore & D. Howell (San Francisco: ASP), 17
Merrill , P. W. & Burwell, C. G. 1950, ApJ, 112, 72
Molinari, S., Liseau, R., & Lorenzetti, D. 1993, A&A Suppl. 101, 59
Morata, O., Estalella, R., Lopez, R., & Planesas, P. 1997, MNRAS, 292, 120
Morata, O., Girart, J. M., & Estalella, R. 2003, A&A, 397, 181
Morata, O., Girart, J. M., & Estalella, R. 2005, A&A, 435, 113
Mundt, R., Stocke, J., & Stockman, H.S. 1983, ApJ, 265, L71
Mundt, R. & Eislöffel, J. 1998, AJ, 116, 860
Neckel, T., Klare, G., & Sarcander, M. 1980, A&AS, 42, 251
Neckel, T. & Staude, H. J. 1984, A&A, 131, 200
Neuhäuser, R., Sterzik, M. F., Schmitt, J. H. M. M., Wichmann, R., & Krautter, J. 1995, A&A, 297, 391
Palla, F. & Stahler, S. W. 1999, ApJ, 525, 722
Parsamian, E. S. 1965, Izv. Akad. Nauk. Armyan. SSR., Ser. Fiz.-Math, 18, 146
Peña, J. H., García-Cole, A., Hobart, M. A., de La Cruz, C., Plascencia, J. C., & Peniche, R. 2003, RMxAA, 39, 171
Polomski, E. F., Woodward, C. E., Holmes, E. K., Butner, H. M., Lynch, D. K., et al. 2005, AJ, 129, 1035
Prato, L., Greene, T.P., & Simon, M. 2003, ApJ, 584, 853
Raga, A. C., Riera, A., Masciadri, E., Beck, T., Böhm, K. H., & Binette, L. 2004, AJ, 127, 1081
Racine, R. 1968, AJ, 73, 233
Reipurth, B., Heathcote, S., & Vrba, F. 1992, A&A, 256, 225
Reipurth, B., Chini, R., Krügel, E., Kreysa, E., & Sievers, A. 1993, A&A, 273, 221
Reipurth, B. & Bally, J. 2001, ARAA, 39, 403
Rice, E. L., Prato, L., & McLean, I. S. 2006, ApJ, 647, 432
Santos, J. F. C., Jr., Bonatto, C., & Bica, E. 2005, A&A, 442, 201
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500,, 525
Simon, M., Ghez, A. M., Leinert, Ch., Cassar, L., Chen, W. P., et al. 1995, ApJ, 443, 625
Solf, J., Böhm, K.-H., & Raga, A.C. 1986, ApJ, 305, 795
Solomon, P. M., Rivolo, A. R., Barrett, J., & Yahil, A. 1987, ApJ, 319, 730
Staude, H. J. & Neckel, Th. 1992, ApJ, 400, 556
Straižys, V., Černis, K., & Bartašiūtė, S. 2003, A&A, 405, 585
Strom, S. E., Grasdalen, G. L., & Strom, K. M. 1974, ApJ, 191, 111
Thé, P. S. 1962, Contributions from the Bosscha Observervatory, 14, 0
Tokunaga, A. T., Reipurth, B., Gässler, W., Hayano, Y., Hayashi, M., et al. 2004, AJ, 127, 444
Visser, A. E., Richer, J. S., & Chandler, C. J. 2002, AJ, 124, 2756
Weaver, H. F. 1949, ApJ, 110, 190
Weaver, W. B. & Jones, G. 1992, ApJS, 78, 239
White, G. J., Casali, M. M., & Eiroa, C. 1995, A&A, 298, 594
Wilner, D. J., Myers, P. C., Mardones, D., & Tafalla, M. 2000, ApJ, 544, L69